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Designing a Decision Support System for Subsurface Activities.

A Meta analysis of the design of a social acceptance motivated decision support system for subsurface activities in the Netherlands

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Abstract

The decision-making process for subsurface activities in the Netherlands has been unable to cope with the driving forces related to social acceptance in several recently proposed subsurface activities. We therefore investigated the possibility to include the triangle of social acceptance in the decision-making process. Our conceptual model relates the stakeholders, their goals and the driving forces to each other. We developed a framework, which describes the interaction between eleven design criteria for a Decision Support System (DSS). This framework will enable us to design a better, from a social acceptance perspective, DSS for subsurface activities in the Netherlands. Since the goals addressed in the decision-making process are very broad and the stakeholders are quite diverse, a single uniform DSS is not able to provide a satisfactory solution. We therefore suggest to design a DSS that is matched with each class of social acceptance.

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1. The need for a change

The opportunities to benefit from the potential of the subsurface gain increased importance in the societal debate. Recent experiences, like the cancelled CO_2 storage project in the Northern Netherlands have shown that social acceptance is imperative for any subsurface activity [1]. The subsurface is the main contributor to our energy supply in the form of fossil fuels. In addition, mining activities provide raw materials for a wide variety of economic activities, like salt mining. New activities like Carbon Capture & Storage (CCS), Nuclear Waste Repositories (NWR), geothermal energy production, shale gas extraction and the underground storage of a wide variety of substances increase the competition for space in the subsurface. The various forms of subsurface development can be interfering or synergetic with each other, depending on the geology, the nature of the activity and the business model of the operator. Interference and synergy are hence becoming driving forces in the decision-making process for subsurface activities. Furthermore, the allocation of benefits and costs among market parties, national government, local governments and host communities has increasingly become a driving force in the decision-making process for subsurface activities [1]. A prime example is the recent gas decision by the Dutch minister of Economic affairs [2], which regulates the gas production level from the Groningen Field in order to mitigate the human-induced earthquakes. Here, technical measures are combined with social and economic incentives for the region. This case is also a clear example of another driving force, namely the increasing societal resistance against subsurface activities. Especially local communities are voicing their opinion in the public debate, often with mixed results, like in the case of the proposed CCS projects in the Netherlands in 2011 [1].

Subsurface exploitation activities are characterised by their long time scale (10 – 50 years), irreversibility in many cases and uncertainties inherent to sparse well sampling and limited imaging techniques. Hence decision-making is complex, which is enhanced by the intensified exploitation of the subsurface. In an increasing number of cases this results in 'spatial conflicts' between activities in the underground. On top of this, competing objectives and differing knowledge levels of the involved stakeholders, such as policy makers, businesses and local residents, further complicate the decision-making process. From the recent experiences, it is clear that the current decision-making process related to subsurface activities has to be updated [1]. The current procedure is based on a limited evaluation of the planned activity, focusing on safety, technical feasibility, and profitability [3]. Other considerations, originating from social or strategic concerns are not accounted for in the Mining Act, which governs the award of exploration and/or development licences. Following Koornneef [4] we agree that the permit procedure needs to be expanded to include a broader range of issues, i.e. horizontal integration. In addition, other potential subsurface activities, i.e. vertical integration, have to be included in order to mitigate the shortcomings of the current decision-making process. However, until now there is no practical application, which explains how this expansion should be executed. Our research is therefore aimed at understanding the requirements for such an expansion, leading to a design of a Decision Support System (DSS) for subsurface activities. As a guiding principle we will use the triangle of social acceptance as described by Wüstenhagen et al. [5]. In the following, we will first discuss this concept and how it can be applied to the decision-making process for subsurface activities. Then we will derive design criteria for a DSS from several research fields and integrate them into a single framework and analyse their interaction. We conclude with a short discussion of our findings.

2. Social acceptance in the decision-making process

The triangle of social acceptance identifies three classes: social-political, market and community acceptance. Each class is characterized by its specific stakeholders and decision-making situation [5]. For the integration of the triangle in the decision-making process, we propose a conceptual model where we relate the three classes to the driving forces in the decision-making process.

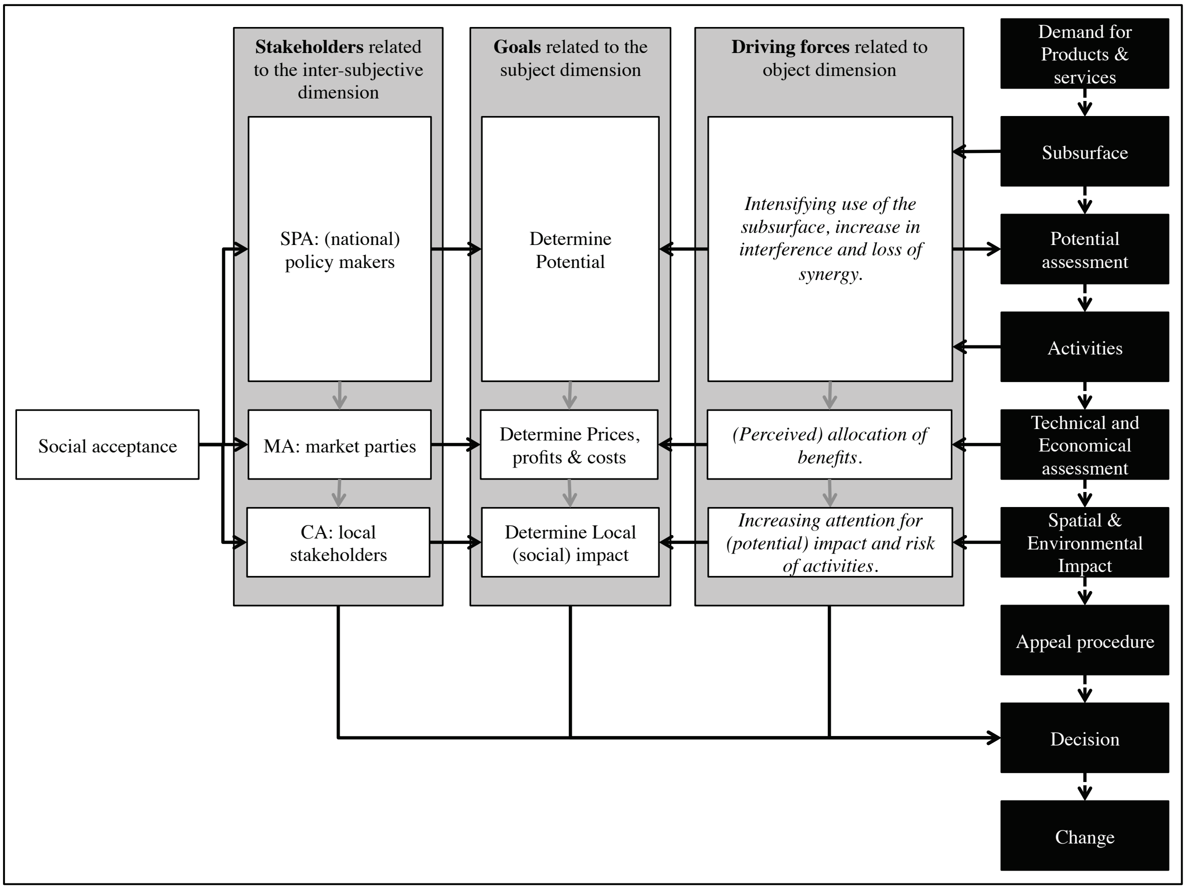

Figure 1: **Integration framework**. Integrating the triangle of social acceptance [5] with the current policy framework and driving forces. The black squares represent the different stages of the decision-making process. The grey squares represent the different dimensions of the decision-making process [6]. The white squares indicate from left to right, the stakeholders for each class of social acceptance, the goals for each class and the driving forces. The arrows indicate the relation between the different elements.

By relating the driving forces with the classes of social acceptance we are able to determine who should be involved in formulating the goal of the decision-making process, in order to accommodate the driving forces. As depicted in Figure 1, each of the three classes of social acceptance has its own set of stakeholders and is focussed upon a certain set of goals. For instance, in the case of *social-political acceptance,* the main goal for policy makers is to gain support for the realization of policy. In order for these policies to be realistic, it is necessary to have an insight in the potential of the subsurface to produce a certain resource or to deliver a service such as storage. Therefore the geological properties of the subsurface and the nature of possible activities need to be understood, including the potential for interference and synergy. In the case of *market acceptance,* the goal is to determine the allocation of benefits and costs between the market participants. Here, the driving force of (perceived) miss-allocation of the benefits is related to the location where these profits and cost are incurred as well as to the distribution of the costs, benefits and external effects. For *community acceptance* the goal is to determine the local impact of the activity, including social and environmental issues as well as the reputation of the project owner. Besides the three classes of social acceptance, the conceptual model also incorporates the three dimensions of the decision-making process [7]. Firstly the inter-subjective dimension, which is related to the question: who are the stakeholders? Secondly, the subject dimension, which is related to the question: how to achieve this goal? Thirdly, the object dimension, which is related to the question: what are the driving forces of the decision-making process?

3. Selecting design criteria

The usefulness of a DSS in a given decision situation is determined by the extent to which it is able to provide the desired results or goal(s) of the decision-making process [8] . The variety of decision aid methods is large [9] . Each method has its "pros" and "cons" and is therefore limited in its applicability throughout the decision-making process [10] . Voogd [8] proposes the following basic distinction between DSS's on the basis of the goal of the decision-making process and the stage it is in. Firstly, one should distinguish between the preparation (*ex ante*) or review (*ex post*) of a planned activity. Secondly, the choice for a DSS should include the assessment whether the number of alternatives for the activity is known or unknown. In the case of an *a priori* decision-making situation not all alternatives or criteria are known. In case of an *a posteriori* decision-making situation all possible alternatives are known. It should be noted that most *ex ante* evaluations of activities within the decision-making process are in fact *a posteriori*. This relates to the nature of evaluations in planning, where a fixed set of criteria are used. This is in contrast with a (political) decision-making process where the number of criteria, or issues, is not fixed and can be time-variant [8]. A third differentiator between methods is their nature, which can be *implicit* or *explicit*. An implicit evaluation focuses on the creation of consensus between stakeholders by facilitating negotiations and participation. This form of evaluation is aimed at process optimisation. Explicit evaluation on the other hand is focussed on the accountability for, or traceability of the results by a systematic analysis. However, more criteria for formulating a DSS exist in other fields[9], some of which are listed below.

In the field of economics, the management of uncertainty and risk identifies the need to distinguish between their nature, level and location.

- The *nature of uncertainty* is related to the extent to which it primarily stems from knowledge imperfection or is a direct consequence from inherent variability of the decision-making situation [11].
- The *level of uncertainty* is determined by the position where it manifests itself in the spectrum between deterministic knowledge and total ignorance [11].
- The *location of uncertainty* relates to the decision-making situation itself, for example uncertain input information, level of importance, results or interaction between elements [11,12].
- Risk is comprised of the likelihood that an event will occur [12] and the severity of impact of the event [12,13].

The field of (spatial) planning provides several insights on different aspects of the decision-making process, see [14]:

- The *rationality of a decision-making process* is related to its objective i.e. goal maximization or process optimization [7] .
- The *knowledge level of the stakeholder* i.e., the extent to which the DSS should enable actor/stakeholder communication is dependent on the knowledge level of the stakeholder and the need to have a shared knowledge base. Furthermore, depending on the knowledge level of the stakeholders involved, the DSS should allow for some degree of defining and structuring the decision-making problem.
- The *measuring scale of the input information* is related to the quality and quantity of the information that is available in the decision-making process.

Studies in the field of Multi Criteria Decision Aid (MCDA) methods [9,10,15] have provided us with several criteria relevant for the design of a DSS.

- The *elucidation mode* indicates the preferred method for determining the level of importance for each criterion. This can be done for example by direct rating through assigning a weight factor to each criterion [9] or by pairwise comparison, in which the dominant criterion for each pair is identified [16].
- The *aggregation optimization mode* determines whether the final score is aggregated on the basis of preference or performance [10].
- *Structure order of results* defines the measuring scale of the results, which can range from total order to a partial interval order [9] i.e. from full quantitative to a qualitative structure.

Despite the richness in design criteria provided in literature, there is no integrated framework in which these aspects are inter-related, especially for subsurface activities with their unique characteristics. We will therefore construct a framework, on the basis of the above described insights, for interrelating these design criteria for a DSS for the subsurface.

4. Decision support system design framework.

The context for our decision-support system for activities in the subsurface is shaped by the uncertainty inherent to that domain. As this uncertainty affects all other criteria, we take it as our starting point. We use the insights from spatial planning to select, for each dimension of the decision-making process, three criteria to approximate the nature of the decision-making process (Figure 2). On the most concrete level, that of DSS, we subsequently select three criteria from MCDA literature that encapsulate all the previous stages of the design process for a DSS [9,10].

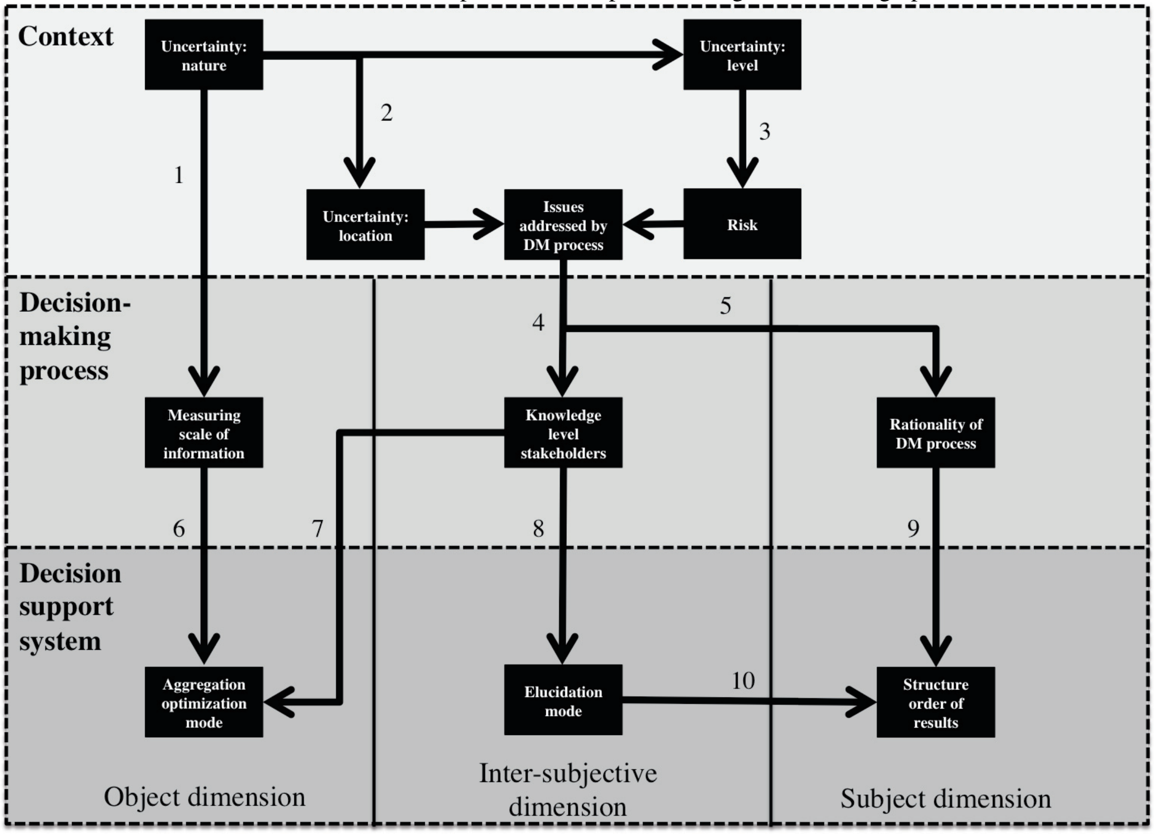

Figure 2: **DSS design criteria framework**. The framework is made up of seven blocks divided over three levels, context (lightest grey), decision-making process, including the inter-subjective, subject and object dimension (medium grey) and decision support system, including the inter-subjective, subject and object dimension (darkest grey). For each block the relevant criteria (black squares) for designing a DSS are indicated. The numbered arrows indicate the relations between these criteria, which will be discussed in Table 1.

In the context block, the main criteria namely the *nature, location and level of uncertainty*, *risk* and *issues addressed by the decision-making process* for a decision-making situation are depicted. The decision-making process and the DSS blocks are divided according to the three dimensions of the decision-making process [7]. Firstly, the object dimension is related to the *measuring scale of (input) information* criteria [10] . Secondly, the inter-subjective dimension is related to the *stakeholders and their knowledge level*. Thirdly, the subject dimension is reflected by the criterion, indicative of the *rationality of decision-making process* [6]. As depicted in Figure 2 the *aggregation optimization mode, elucidation mode and structure order of results* are dependent on the previously mentioned variables from the other blocks.

The interaction between these criteria affects the value of an individual criterion in the context, decision-making process and decision support system blocks. We will discuss each of these interactions from the perspective of social acceptance, limiting ourselves to the most relevant interactions, see Table 1.

Relation number	Relation	Argumentation
1	**Uncertainty nature** versus **measuring scale of information**	The nature of uncertainty reflects its origin, ranging from knowledge imperfection to inherent variability of the object [11]. Therefore, depending on the nature, the measuring scale of the input information will be affected.
2	**Uncertainty location** versus **issues addressed by decision-making process**	The uncertainty related to the location i.e. context refers to the conditions and circumstances that underlie the choices and boundaries of the issues that need to be addressed [11].
3	**Uncertainty level** versus **Risk**	The nature of uncertainty refers to the knowledge level in which a future situation can be understood, ranging between complete deterministic understanding and total ignorance [12,17]. The level of uncertainty will affect the probability component of a risk. Meaning that uncertainty is related to cases in which "there is no valid base of any kind for classifying instances" [17]. A priori probabilities and statistical probability are related to risk[17].
4	**Issues addressed by decision-making process** versus **knowledge level stakeholders**	The issues addressed in the decision-making process are related to the stakeholders and their knowledge level through the problem solution procedure, also known as "problematics" [18]. Depending on the interaction between the issues and knowledge level the most appropriate problem solution procedure can be selected: choice or selection, sorting or assignment, ranking or ordering and descriptive or cognitive [18].
5	**Issues addressed by decision-making process** versus **rationality of decision-making process**	The rationality of the decision-making process is related to the level of governance and the breadth of the goal(s) of the decision-making process [7,18]. The scope of the issues in the decision-making process determine the relevant stakeholders i.e. the level of governance. The nature of the issues addressed in the decision making process, determines the goal of the decision-making process [7,18].
6	**Measuring scale of information** versus **aggregation optimization mode**	The measuring scale of information is related to quality of the information. Together with the quantity they are the major factors for selecting the aggregation optimization mode [10].
7	**Knowledge level stakeholders** versus **aggregation optimization mode**	The knowledge level of the stakeholders affects the problem solution procedure, which in turn will determine the appropriate aggregation optimization mode [10]. In addition the degree in which stakeholders accept some level of compensation between evaluation criteria will affect the aggregation optimization mode [19].
8	**Knowledge level stakeholders** versus **elucidation mode**	The preferred elucidation mode is to a large degree determined by the nature of the stakeholder and its knowledge level and familiarity with a certain elucidation mode [10,20-22].
9	**Rationality of decision-making process** versus **structure order of results**	Each form of rationality has a tolerance for a certain structure order of results, i.e. to extent to which the results structure order corresponds to the problem solution procedure[6,18].
10	**Elucidation mode** versus **structure order of results**	Each elucidation mode will yield a different structure order of result. Direct weighting will result in a total order but pairwise comparisons may result in a different structure order depending on the preference for each criterion under evaluation [10].

Table 1: **Design criteria**. The number of the relation, as depicted in Figure 2, is shown in the left column. The middle column depicts the relation between criteria. The right column contains the arguments for each relation.

From Table 1 we can derive that there remains some ambiguity in the argumentation, because we have limited ourselves to the main interaction mechanisms. For example in the case of relation number eight the nature and familiarity of the stakeholder affect, besides knowledge level, the choice for an elucidation mode. In setting up the Table, we used the concept of problematics only as a tool to explain the relation between several design criteria and not as a separate design criterion in our framework. The reason for this choice is that other aspects affect problematics itself and we are interested in underlying aspects like the issues addressed in the decision-making process. Despite these limitations, we integrate all criteria into a single framework, which allows a structured understanding of the interaction between them. In addition, the framework provides a structured way to design a DDS, which is relatively easy to convey to final end users, i.e. the stakeholders in the process. Furthermore, we derive from Figure 2 and Table 1 that the issues addressed in the decision-making process and the involved stakeholders play a pivotal role in the design of a DSS. This is caused by the interaction between these design criteria and other relevant design criteria for a DSS, like rationality, aggregation mode and elucidation mode. In addition, as described in Section 2, the issues and stakeholders usually represent a high degree of diversity. It is therefore very unlikely that a single uniform DSS is able to provide a satisfactory solution. We therefore suggest to design a DSS that is tailor made to each set of stakeholders and their objectives. We are confident, on the basis of a previous study by van Os et al [1] , that the classes of social acceptance can serve as a suitable means for selecting these sets of stakeholders and corresponding goals.

5. Conclusions and Discussion.

The current decision-making process for subsurface activities in the Netherlands is unable to cope with all the driving forces, which are associated with these activities. In order to improve this situation, we investigate the potential of applying the triangle of social acceptance. We integrate this concept into the decision-making process and are thus able to connect stakeholders with driving forces in combination with the identification of the goals of the decision-making process. From the field of economics, (spatial) planning and MCDA we gained several insights about important design criteria for a DSS such as the difference between uncertainty and risk, the rationality of the decision-making process and the cause and effect of different ways of interpreting, aggregating and evaluating. Furthermore, by arranging the design criteria according to their stage in the design process of a DSS and to the dimension of the decision-making process, we are able to identify the relation between all relevant design criteria from a social acceptance perspective. Our framework shows that by integrating insights from different fields we were able to add some innovative new elements to decision-making processes for subsurface activities in the Netherlands. We are aware that our framework is limited in the number of interactions we analysed. However we believe that at this stage of integrating social acceptance in a DSS, clarity and comprehensibility should prevail above comprehensiveness. Further research, including test cases, will determine to which extent our framework has to be expanded in order to produce a practical application. Despite these limitations, we believe that the criteria reported in our study provide new building blocks for the design of a DSS for subsurface activities in the Netherlands, in particular by including the main interactions between the design criteria. In addition, the incorporation of the triangle of social acceptance allows for a more profound insight in how to expand the decision-making process, since it enables the identification of the stakeholders who should be involved in the different stages of the decision-making process. This leads to the realization that given the diversity of the stakeholders and their goals, a single uniform DSS is most likely not able to provide a satisfactory solution. Therefore, in future research we want to focus on designing a DSS that is tailor made for each class of social acceptance.

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